結合物聯網、進階控制的創新型熱泵低溫乾燥系統之研究

An Investigation of Innovative Low-Temperature Heat Pump Drying System with Integrated IoT and Advanced Control Technologies

October 13, 2017
at
National Taipei University of Technology

林益海教授, Paul I-Hai Lin, P.E. States of IN and CA
Professor of Electrical and Computer Engineering Technology
pilin@purdue.edu www.etcs.ipfw.edu/~lin
Purdue University Fort Wayne (美國普渡大學韋恩堡校區)

(國立台北科大電資學院 榮譽國際講座教授)
Honorary International Chair Professor
National Taipei University of Technology, 2014-2017

Topics of Discussion (研討綱要)

I. Heat Pump Assisted Low-Temperature Drying Technology and Applications (熱泵低温乾燥科技與用途)

II. Review of Heat Pump Drying Technology (現有熱泵乾燥科技之檢閱)

III. Architecture Design of a New Heat Pump for Low-Temperature Drying (熱泵低温乾燥系統之架構設計)

Topics of Presentation (演講大綱)

IV. Integration of IoT, Advanced Control Technology and Heat Pump Drying System (物聯網, 進階控制與熱泵低温乾燥系統之整合)

V. IoT-Enabled Sensors and Actuators (支援物聯網的感測器與驅動器)

VI. IoT-based Heat Pump Drier Monitoring and Control System and Strategies (以物聯網為主的熱泵乾燥機監測控制系統及策略)

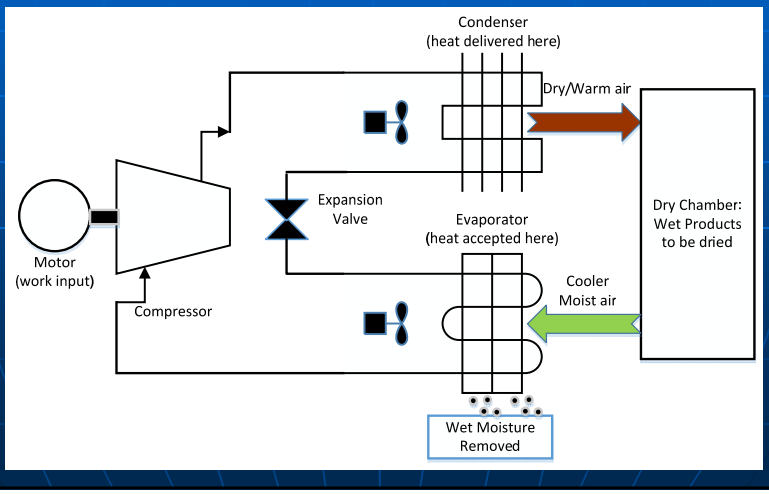
VII. Summary and Conclusion (結論)

I. Heat Pump Assisted Low-Temperature Drying Technology and Applications[1] (熱泵低温乾燥科技與用途)

- Applications
  - Crop drying
    - Rice, corn, wheats
  - Fruit drying
    - Logan, Litchi, Pineapple, Mangos, Bananas, Dates, Figs, Berry, Cherry
  - Vegetable drying
    - Gingers, Tomato, Beans
  - Herb drying
  - Seafood drying

II. Review of Heat Pump Drying Technology (現有熱泵乾燥科技之檢閱)

- [2]Simple schematic of mechanically driven heat pump was discussed in "Industrial Heat Pumps for Steam and Fuel Saving - A Best Practice Brief," Energy Efficiency and Renewable Energy, U.S. Dept. of Energy.



5

II. Review of Heat Pump Drying Technology (continue) (現有熱泵乾燥科技之檢閱)

Heat Pump Crop Drying System Studied, 1984-1986, at Purdue University[3] (普渡大學所作的熱泵農作物乾燥系統研究)

- **Applicability: Grain drying, mid-size grain farm operations**
- **End Uses: Crop drying, moisture removal, quality control**
- **The 14.6 kW Heat-pump unit was installed on a 4,000 bushel drying bin, compared to that of a similar size fan system (30.7kW total) with a 24kW resistance heater.**
- **The electricity demand for the heat pump unit was 52% lower**
- **The operating cost of removing each percentage point of moisture per bushel was 0.181 kWh for the heat pump and 0.293 kWh for resistance fan system**

6

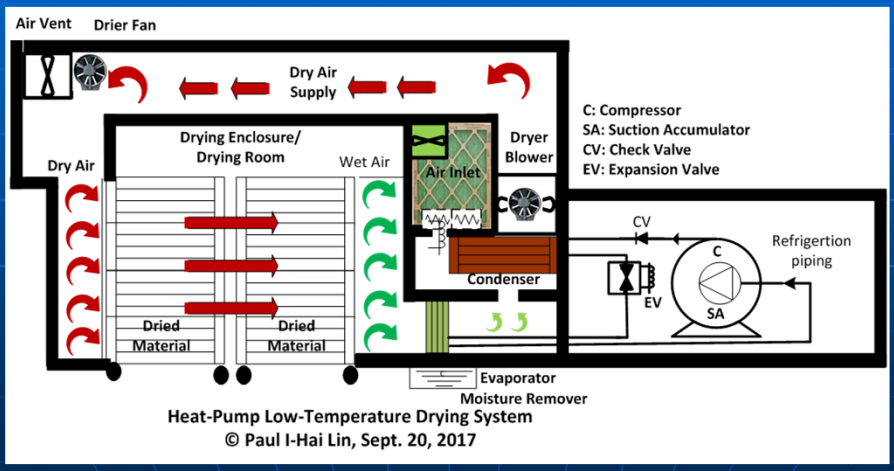
II. Review of Heat Pump Drying Technology (continue)
(現有熱泵乾燥科技之檢閱)

- The paper[4] reported design, energy consumption, operation modes and criteria and influence of product quality of heat pump dryers.
- "A system for food drying using humidity control and low temperature"[5] using scientific approach was discussed in 2008.
- A work on "improvements of high-temperature drying heat pumps"[6] was presented at International Refrigeration and Air Conditioning Conference in 2010.
- The paper[7] investigated the performance of an air source heat pump for drying purpose in 2010.

II. Review of Heat Pump Drying Technology (continue)
(現有熱泵乾燥科技之檢閱)

- A high-efficiency heat pump system and related applications[8] was reported in 2013, which achieves the highest hot air temperature of 65 ºC, cold water temperature of 12 ºC, and a COP (coefficient of performance) above 3.6.
- The paper[9] reported an experimental system and tests to optimize a tomato drying process using both hot-air convection system and microwave system.
- An experimental investigation of the fruit drying performance of a heat pump dryer[10] was reported in 2014.

III. Architecture Design of New A Heat Pump for Low-Temperature Drying
(熱泵低溫乾燥系統架構設計)



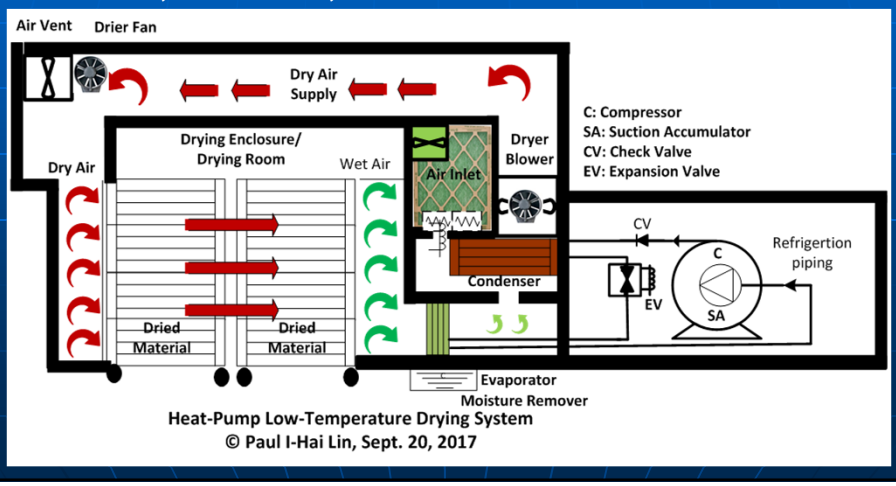
III. Architecture Design of New A Heat Pump for Low-Temperature Drying
(熱泵低溫乾燥系統架構設計)

- **Major Components**
  - Compressor
  - Two Heat Exchangers: Evaporator, Condenser
  - Expansion devices
  - Air ducts

III. Architecture Design of New A Heat Pump for Low-Temperature Drying
(熱泵低溫乾燥系統架構設計)

System Operation (系統操作原理)

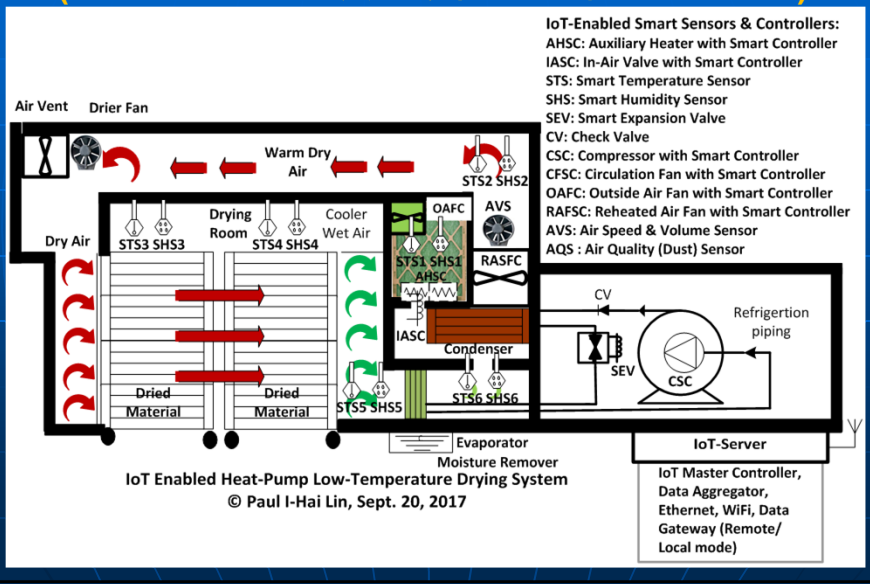
- Two Heat Exchangers: Evaporator, Condenser, Expansion devices, Check valve, Air ducts



Heat-Pump Low-Temperature Drying System

© Paul I-Hai Lin, Sept. 20, 2017

IV. Integration of IoT, Advanced Control Technologies and Heat Pump System
(物聯、進階控制與熱泵低溫乾燥系統之整合)



IoT Enabled Heat-Pump Low-Temperature Drying System

© Paul I-Hai Lin, Sept. 20, 2017

IV. Integration of Advanced Control Technologies to Heat Pump Dryer System
(物聯網, 進階控制與熱泵低温乾燥系統之整合)

- Inverter controlled compressor
- Variable speed blower
- Computer-based digital controller: Industrial computer, Programmable Logic Controller (PLC), Touch panel
- Sensors and actuators

IoT Enabling Technologies and Supporting Infrastructures

- Smart sensors technologies
- Wired/wireless communications and Internet
- Micro-electronics subsystems
- IoT Server, IoT-enabled sensor and actuators
- Distributed computing systems
- Cloud computing services
- Database, Datacenter
- Big data and analytic

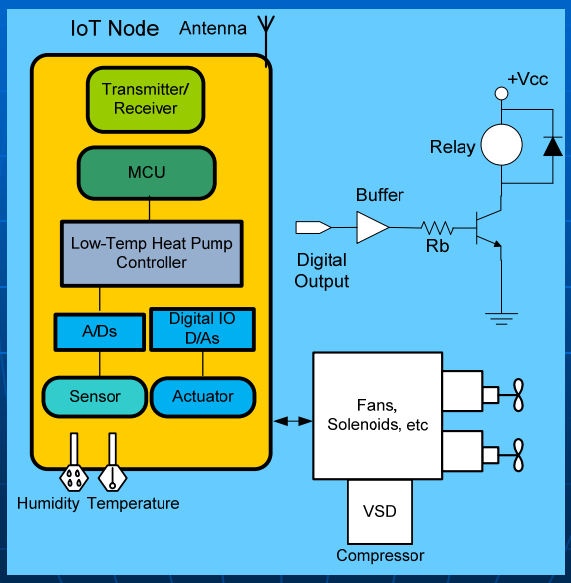
V. IoT-Enabled Sensors and Actuators (支援物聯網的感測器與驅動器)

- **What is IoT (Internet of Things)?**
- IoT includes: “Internet” & “Things”
  - Local networking, communication, and Internet-based remote access
  - States of Things – our most interested data & info in Heat Pump Dryer Systems
    - Dryer system parameters: temperature, relative humidity, air flow rate, air flow volume, air quality (dust)
    - Refrigeration piping system, Refrigerant flow regulators and valves
    - Electric parameters: current, voltage, power, service time, problems

V. IoT-Enabled Sensors and Actuators (支援物聯網的感測器與驅動器)

- **IoT-enabled Sensors**
  - Temperature sensor
  - Humidity sensor
  - Air flow sensor
  - Air volume sensor
  - Air quality (dust) sensor
- **IoT-enabled Actuators**
  - Compressor controller
  - Expansion Valve, Condenser Valve
  - Fans, Solenoid valve

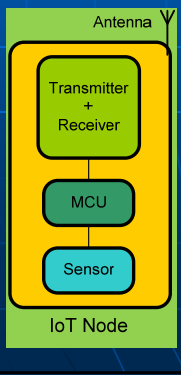
V. IoT-Enabled Sensors and Actuators
(支援物聯網的感測器與驅動器)

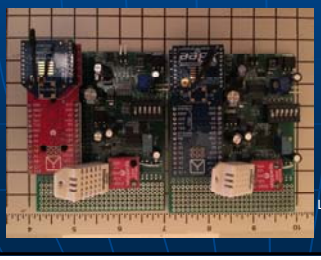


17

IoT Sensor Nodes (IoT感測器)

- **IoT sensor nodes = Smart devices**
  - Sensors, Analog electronics & Signal processing, Embedded processor, Communication Units, Programs
  - Smart sensors: Humidity, temperature, air flow, etc



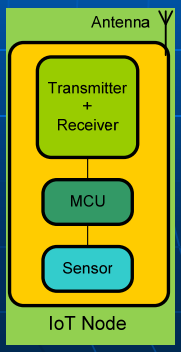


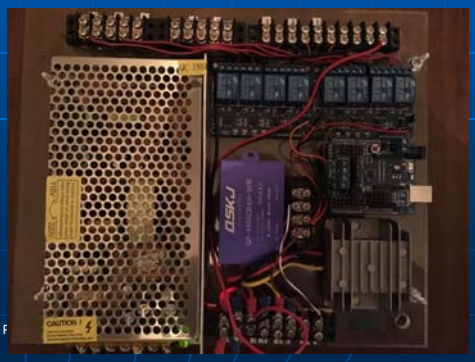
Lin

18

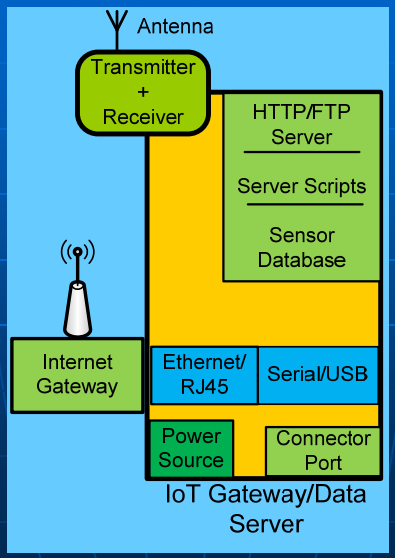
IoT Actuator Nodes (IoT 驅動器)

- **IoT Actuator Nodes = Smart Actuators**
  - Relay, Solid State Relay (SSR), Analog electronics & Signal processing, Embedded processor, Communication Units, Programs
  - Smart Actuators: SSR, Relay, Blower, Fan, Expansion valve controller, Compressor controller, etc



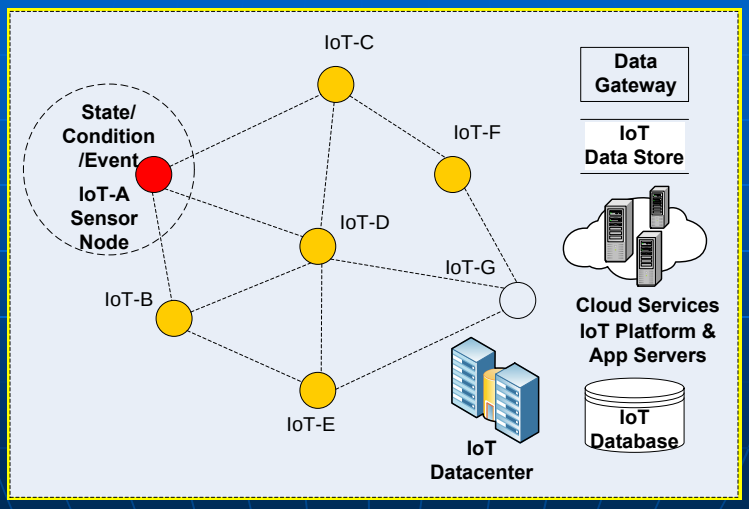


IoT Gateway and Data Server

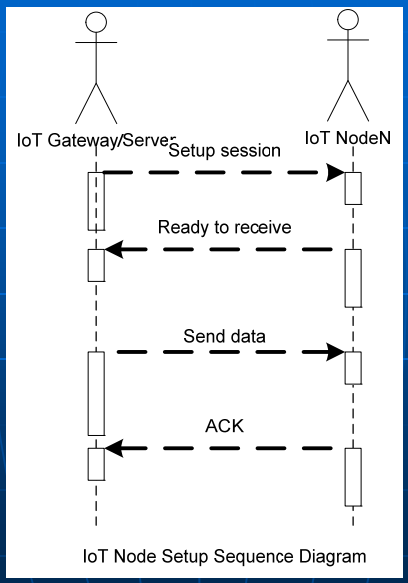


20

IoT Server, Enabling Technologies ad Supporting Infrastructures

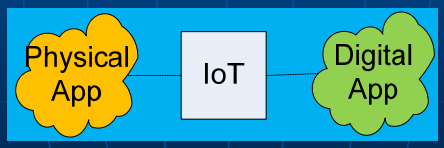


IoT Gateway and IoT Node Setup Sequence Diagram



VI. IoT-based Heat Pump Drier Monitoring and Control System and Strategies
(以物聯網為主的熱泵乾燥機監測控制系統及策略)

- Real-time, remote data access, 7/24/365 around the clock
- Data logging and trending
- Intelligent system monitoring and control
- System tuning based on farm product types
- Job finish notification



VI. IoT-based Heat Pump Drier Monitoring and Control System and Strategies
(以物聯網為主的熱泵乾燥機監測控制系統及策略)

Adaptive Intelligent Control Schemes

- Estimation of system humidity loads
- Calculation of moisture loads
- Fuzzy logic control of moisture content
- PID precision control of moisture content
- Neural Network for system parameters learning

VI. IoT-based Heat Pump Drier Monitoring and Control System and Strategies
(以物聯網為主的熱泵乾燥機監測控制系統及策略)

Adaptive Intelligent Control System

- **Control Parameters**
  - Dehumidification rate
  - Compressor/Refrigerant flow rate control
  - Air flow rate through Evaporator
  - Air flow rate through Condenser
  - Air mixing factor (outside air + system air)
  - Temperature
  - Humidity

VI. IoT-based Heat Pump Drier Monitoring and Control System and Strategies
(以物聯網為主的熱泵乾燥機監測控制系統及策略)

MIMO Adaptive Intelligent Control System
(Multiple-Input Multiple Output)

- Input Variables
  - **Dry Room Temperature**
  - **Dry Room Humidity**
  - **Dehumidifier Rate**
- Output Variables
  - **Evaporator Fan Speed: Air flow rate through Evaporator**
  - **Condenser Fan Speed: Air flow rate through Condenser**
  - **Dry Air Fan Speed**
  - **Air Mixing Fan Speed**
  - **Compressor speed (RPM, VSD control)**

Other Smart Features and Settings

Heat Pump Drier Automatic Operations

- Improved serviceability
- Reduced unplanned downtime
- Greater asset availability and reliability
- Optimized operation and reducing energy cost
- Security and Risk Management
  - Act or react to people and machines in a nonintrusive manner

VII. Summary and Conclusion

結論

References (參考文獻)

1. 行政院農委會水土保持局,106年度,農產品低溫保質、創價乾燥技術培訓計畫; 翁國亮, 蔡貴義, 林益海; 執行期限106年9月1日至106年11月30; (Low-Temperature Drying Technology for Preserving Agricultural Products with Added Values, A training project; PI Kuo-Liang Weng , Co-Pis: Kuei-I Tsai, and Paul I-Hai Lin; approved by Soil and Water Conservation Bureau, Council of Agriculture, Executive Yuan, Taiwan, project period Sept. 1 to Nov. 30, 2017) 。
2. "Industrial Heat Pumps for Steam and Fuel Saving," Energy Efficiency and Renewable Energy, U.S. Dept. of Energy, June 2003, https://energy.gov/eere/amo/downloads/industrial-heat-pumps-steam-and-fuel-savings
3. "Crop Drying with Heat Pumps," U.S. National Food & Energy Council, Inc, Columbia, Missouri, http://www.ensave.com/wp-content/uploads/2013/12/CropDryingWithHeatPumps.pdf
4. "Heat Pump Drying – New Technologies and Operational Modes for Production of a New Generation of High Quality Dried Products, ," Trygve M. Eikevik, Odilio Alves-Filho, and Ingvald Strommen, https://www.researchgate.net/publication/267200414_HEAT_PUMP_DRYING_-_NEW_TECHNOLOGIES_AND_OPERATIONAL_MODES_FOR_PRODUCTION_OF_A_NEW_GENERATION_OF_HIGH_QUALITY_DRIED_PRODUCTS
5. "A System for Food Drying Using Humidity Control and Low Temperature," Pasquale Catalano, Flavio Fucci, Ferruccio Giametta, and Givoanna La Fianza, The CIGR E Journal Manuscript FP 07 012, Vol X, Jan. 2008, http://www.cigrjournal.org/index.php/Ejounral/article/viewFile/1011/1004.

References (參考文獻)

6. "Improvements of High-Temperature Drying Heat Pumps," Vasile Minea, International Refrigeration and Air Conditioning Conference at Purdue, July 12-15, 2010, Purdue University e-Pubs, http://docs.lib.purdue.edu/iracc/1103.
7. "Air Source Heat Pump System for Drying Application," R. Daghigh, M. H. Ruslan, A. Zaharim, and K. Sopian, Selected Topics in System Science and Simulation in Engineering, ISSN 1792-507X, http://www.wseas.us/e-library/conferences/2010/Japan/ICOSSSE/ICOSSSE-63.pdf
8. 高效率熱泵冷凝乾燥系統應用研究; 蔡禮棟, 邱相文, 蔡致榮, 林建志; 102年度農業工程自動化計畫成果研討會論文集, 台灣,台中市, http://ir.tari.gov.tw:8080/bitstream/345210000/6183/2/no177-8.pdf.
9. "Experimental System and Tests to Optimize a Tomato Drying Process," P. Catalano, F. Fucci, F. Giametta, A. La Penna and G. La Fianza, The Open Agriculture Journal, 2013, 7, 73-79, https://benthamopen.com/contents/pdf/TOASJ/TOASJ-7-73.pdf
10. "An Experimental Investigation of the Fruit Drying Performance of a Heat Pump Dryer," Adonis A. Closas, and Prof. Eliseo P. Villanueva, ICBAES, Dec. 8-9, 2014, http://iaast.org/upload/6772A1214036.pdf.
11. 熱泵乾燥系統的溫濕度控制策略; 蔡貴義 (Kuei-I Tsai), 蔡峻銘 (Juyun-Ming Tsai); 2013綠色科技工程與應用研討會 (GTEA), May 24, 2013, http://ir.lib.ncut.edu.tw/bitstream/987654321/4200/3/E11.pdf
12. "Thermodynamic analysis of PID temperature controlled heat pump system," Ali Etem Gurel, Ilhan Ceylan, Case Studies in Thermal Engineering 2 (2014) 42-49, http://www.sciencedirect.com/science/article/pii/S2214157X13000142.

References (參考文獻)

13. “Energy Analysis of PID Controlled Heat Pump Dryer,” Ilhan Ceylan, Engineering, 2009, 1, 188-195, Scientific Research, http://file.scirp.org/pdf/Engineering20090300007_81490668.pdf
14. Tutorial Course on C/C++ with Fuzzy Logic Control Applications," 153 pages, 1994 IEEE Industry Applications Society Annual Conference, Denver, Colorado, October 2, 1994,
15. "Development of Fuzzy Logic Processing Objects for Industrial Control Applications," Paul I-Hai Lin, 1993 IEEE Industry Application Society Record, pp. 2021-2026
16. “IIoT, Cloud Computing, and Energy Management: Challenges and Opportunities,” Paul I-Hai Lin, a talk at National Chin-Yi University of Technology, Taichung, Taiwan, June 15, 2016, http://www.etcs.ipfw.edu/~lin/Presentation/2016-6-15/Lin-ChinI-UofTechOn-IIoT-Cloud-EnergyManagementTalk-2016-6-15.pdf.
17. “IoT/IIoT Technologies, Trends and Strategies: Challenges and Opportunities,” Paul I-Hai Lin, March 8, 2017, a talk at National Chin-Yi University of Technology, Taichung, Taiwan, http://www.etcs.ipfw.edu/~lin/Presentation/2017-3-8/Lin-ChinI-UofTechOn-IIoT-TechTrendTalk-2017-3-8.pdf.